MIL-HDBK-1002/6
30 JUNE 1987
SUPERSEDING
NAVFAC DM-2.06
May 1980

MILITARY HANDBOOK

ALUMINUM STRUCTURES, COMPOSITE STRUCTURES, STRUCTURAL PLASTICS, AND FIBER-REINFORCED COMPOSITES

NO DELIVERABLE DATA REQUIRED BY THIS DOCUMENT

DISTRIBUTION STATEMENT A. APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

AREA FACR

ABSTRACT

Basic criteria for the design of structural elements and systems fabricated of miscellaneous non-conventional structural materials and composites of several materials are presented for use by experienced engineers. Structural design criteria, as available, and design guidance are included for aluminum structures, for composites of timber and precast concrete construction with cast in-place concrete, for structural sandwich panels, and for structural plastics, fabric tensioned structures, and fiber-reinforced plastics and concrete. Applications guidelines and design cautions are given for guidance in the use of aluminum structures and structural plastics and fiber-reinforced composite components in appendixes.

PAGE iii IS INTENTIONALLY BLANK

FOREWORD

This Military Handbook has been developed from an evaluation of facilities in the Shore Establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. It uses to the maximum extent feasible, national professional society, association, and institute standards. Deviations from this criteria, in the planning, engineering, design, and construction of naval shore facilities, cannot be made without prior approval of NAVFACENGCOM Headquarters Code 04.

Design cannot remain static any more than can the functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged and should be furnished to Naval Facilities Engineering Command, Northern Division, Code 406, Building 77 Low, U.S. Naval Base, Philadelphia, PA 19112, telephone (215) 897-6090.

This handbook shall not be used as a reference document for procurement. Do not reference it in Military or Federal Specifications or other procurement documents.

STRUCTURAL ENGINEERING CRITERIA MANUALS

Number	Title
MIL-HDBK-1002/1	Structural Engineering General Requirements
MIL-HDBK-1002/2	Loads
MIL-HDBK-1002/3	Steel Structures
DM-2.04	Concrete Structures
MIL-HDBK-1002/5	Timber Structures
MIL-HDBK-1002/6	Aluminum Structures, Composite Structures, Structural Plastics, and Fiber-Reinforced Composites
DM-2.08	Blast Resistant Design
DM-2.09	Masonary Structural Design for Buildings (Tri-Service) Change 1 Change 2

When Design Manuals (DM) are revised, they will be converted to Military Handbooks (MIL-HDBK).

NOTICE OF CHANGE

INCH-POUND

MIL-HDBK-1002/6
NOTICE 1
8 September 1997

DEPARTMENT OF DEFENSE HANDBOOK

ALUMINUM STRUCTURES, COMPOSITE STRUCTURES, STRUCTURAL PLASTICS, AND FIBER-REINFORCED COMPOSITES

TO ALL HOLDERS OF MIL-HDBK-1002/6:

1. THE FOLLOWING PAGES OF MIL-HDBK-1002/6 HAVE BEEN REVISED AND SUPERSEDE THE PAGES LISTED:

NEW PAGE	DATE	SUPERSEDED PAGE	DATE
vii	30 June 1987	vii	Reprinted without change
viii	8 September 1997	viii	30 June 1987
11	30 June 1987	11	Reprinted without change
12	8 September 1997	12	30 June 1987

2. RETAIN THIS NOTICE AND INSERT BEFORE TABLE OF CONTENTS.

3. Holders of MIL-HDBK-1002/6 will verify that page changes and additions indicated above have been entered. This notice page will be retained as a check sheet. This issuance, together with appended pages, is a separate publication. Each notice is to be retained by stocking points until the handbook is completely revised or canceled.

Custodian:
Navy - YD2

Preparing Activity:
Navy - YD2
(Project FACR-1174)

AMSC N/A

AREA FACR

ALUMINUM STRUCTURES, COMPOSITE STRUCTURES,
STRUCTURAL PLASTICS, AND FIBER-REINFORCED COMPOSITES

CONTENTS

REPRINTED WITHOUT CHANGE

SUPERSEDES PAGE VIII OF MIL-HDBK-1002/6.

Page

APPENDIXES

PAGE ix INTENTIONALLY BLANK

Section 1: INTRODUCTION

1.1 Scope. This handbook prescribes criteria for the design of structures (including temporary structures) that are fabricated of structural aluminum, composites of timber and precast concrete construction with cast-in-place concrete, structural sandwich panel construction, and structural plastics and composites. Other materials, for which there are no commonly recognized standards of design (reinforced gypsum concrete, bamboo reinforced concrete, and adobe are examples) and which, accordingly, are not covered in this handbook, may be used for structural purposes under the provisions of Paragraph 3 of NAVFAC MIL-HDBK-1002/1, General Requirements.

1.2 Cancellations. This handbook, MIL-HDBK-1002/6, Aluminum Structures, Composite Structures, Structural Plastics and Composites, cancels and supersedes NAVFAC DM-2.06, Aluminum Structures, Composite Structures, Structural Plastics and Fiber Reinforced Composites, May 1980.

1.3 Related Criteria. All documents referenced in this handbook are listed in REFERENCES. Publications from which criteria in this handbook were developed but not specifically referenced, as well as suggested readings, are included in the BIBLIOGRAPHY.

2.1 Scope.

2.1.1 Types of Structures Covered. Recommended standard design criteria for aluminum structural systems in primary structural applications for Class A, B, and C structures are given in Paragraph 2.2. These may also be used for semistructural applications such as curtain wall, door and window framing, ladders, and scaffolding. See MIL-HDBK-1002/1 for definitions of Class A, B, and C structures.

2.1.2 Structures Not Covered. The recommended design criteria given herein are not intended for use in aircraft or ship design.

2.1.3 Guidance. Applications guidelines and cautions are given in Appendix A.

2.2 Design Criteria.

2.2.1 Selection of Alloy. Use only those alloys for which design specifications are available for primary structural applications such as bridges, building frames, towers, stacks, tanks, and bins. Refer to Table 1 in Aluminum Association (AA) Engineering Data for Aluminum Structures. The most frequently used alloys for bridge and building structure applications are 6061 and 6063.

2.2.2 Standard Design Criteria.

2.2.2.1 For Class A Structures. Follow American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges for design loads. Design in accordance with Aluminum Association, Specifications for Aluminum Structures, using allowable stresses for bridge type structures.

2.2.2.2 For Class B Structures. Follow applicable local building codes. Design in accordance with Aluminum Association Specifications for Aluminum Structures, using allowable stresses for building type structures.

2.2.2.3 For Class C Structures. Design in accordance with Aluminum Association, Specifications for Aluminum Structures, using allowable stresses for building type structures, or with factors of safety modified in accordance with customary or standard practice used for n_Tu, n_Tv, or n_Ta in the general formulas in Table 3.3.6 of the above reference.

2.2.2.4 Additional Aluminum Association References for Design Assistance.

(1) Commentary on Specifications for Aluminum Structures.

(2) Engineering Data for Aluminum Structures.

(3) Illustrative Examples of Design.

(4) Welding Aluminum.

2.2.3 Bolted Connections.

2.2.3.1 Standard Criteria: Aluminum Association Specifications for Aluminum Structures.

2.2.3.2 Minimum Connections: Use a minimum of two fasteners in any connection (not including pinned or welded connections) except for secondary bracing members such as lacing and battens and except for incidental connections (not including primary bracing members) not proportioned on the basis of calculated stress.

2.2.3.3 Steel Bolts. Stainless steel bolts (and washers) may be used in aluminum structures without precautions for corrosion isolation. Carbon and alloy steel bolts may be used if galvanized or cadmium-plated. Use galvanized or cadmium-plated washers. However, cadmium plating should not be used for exterior exposures unless the cadmium coating is applied by painting. For design criteria, refer to Design Criteria for Bolted and Riveted Joints, Fisher, John, and Struck, John.

2.2.3.4 Connections Between Aluminum and Carbon Steel. Use aluminum bolts when aluminum and carbon steel are connected by bolting. The carbon steel surfaces and bolt holes shall be isolated from direct contact with the aluminum plate or bolt material, usually by a suitable coating.

2.2.3.5 Eccentricity. Due to lack of yield distortion, effects of eccentricity in connections may not be neglected with aluminum structures.

2.2.3.6 Installation. Use care not to over-torque aluminum bolts. Molybdenum disulfide may be used as a lubricant for threads to minimize torque required.

2.2.4 Welded Connections.

2.2.4.1 Standard Criteria: Aluminum Association Specifications for Aluminum Structures.

2.2.4.2 Additional Guidance: Aluminum Association Welding Aluminum and American Welding Society (AWS) Welding Handbook.

2.2.5 Curtain Wall Structural Criteria. The following publications of the American Architectural Manufacturers Association provide design and specifications guidance:

(1) Curtain Wall Design Guide Manual (CW-1-9).

(2) Curtain Wall Manual #11 (CW-11): Design Wind Loads for Buildings and Boundary Layer Wind Tunnel Testing Manual (as supplemental guidance to MIL-HDBK-1002/2, Loads, which governs where applicable).

(3) Curtain Wall Manual #12 (CW-12): Structural Properties of Glass.

(4) Methods of Test for Metal Curtain Walls, AAMA 501-83.

2.2.6 Aluminum Towers and Antennas.

2.2.6.1 Allowable Stress for Wind Loads. Do not use the one-third increase in allowable stress for wind load permitted in the Aluminum Association Specifications for Aluminum Structures.

2.2.6.2 Other Design Criteria:

(a) Use applicable criteria in Electronics Industries Association (EIA) Standard RS-222-C, Structural Standards for Steel Antenna Towers and Antenna Supporting Structures.

(b) Follow general design criteria and guidance given in Paragraph 4.3 of MIL-HDBK-1002/3, Steel Structures.

2.2.7 Aluminum Stacks, Tanks, and Bins. Follow the design guidance and general references given in Paragraphs 4.4, 4.5, and 4.6 of MIL-HDBK-1002/3.

Section 3: COMPOSITE STRUCTURES

3.1 Scope. This section covers design guidance for structures that comprise two or more types of structural materials and that derive increased strength and stiffness from being bonded or connected together to act as an integral structural section. The following structural types are covered:

(1) Cast-in-place concrete bonded or mechanically connected to pre-cast concrete.

(2) Cast-in-place concrete bonded and mechanically connected to structural timber.

(3) Sandwich panels having relatively stiff and strong structural facings bonded to lightweight cores of lesser strength and stiffness and lower unit volume cost.

Composite cast-in-place concrete and structural steel or metal deck systems are not covered in this section since design criteria and guidance for these systems are given in MIL-HDBK-1002/3. This is because the principal standard design criteria for steel-concrete composite systems are included in structural steel and metal decking standards.

This section does not cover composite materials such as fiberglass-reinforced plastics or fiber-reinforced concrete. These materials are discussed in Section 4 in this handbook.

3.2 Cast-in-Place Concrete - Precast Concrete Composite Construction.

3.2.1 Class A Structures. Design in accordance with American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges.

3.2.2 Class B and C Structures. Design in accordance with American Concrete Institute (ACI) 318 Building Code Requirements for Reinforced Concrete. Chapter 17 gives criteria for composite concrete flexural members.

3.2.3 Additional Criteria and Guidance. Refer to Prestressed Concrete Institute (PCI) Design Handbook, Precast and Prestressed Concrete, and PCI Manual for the Design of Hollow Core Slabs.

3.3 Cast-in-Place Concrete - Timber Composite Construction.

3.3.1 Class A Structures. Design in accordance with AASHTO Standard Specifications for Highway Bridges.

3.3.2 Class B and C Structures. Design in accordance with National Forest Products Association National Design Specification for Wood Construction for the timber portion and ACI 318 Building Code Requirements for Reinforced Concrete for the concrete portion.

3.3.3 Additional Criteria and Guidance. Refer to American Institute of Timber Construction (AITC) Timber Design Handbook, 2nd Edition, 1974, Chapter 6, pp. 122 to 133, for typical practice used in the past. Note that the second edition of the above reference is not the current edition and is now out of print. Concrete-timber composite structures are seldom used in current structural engineering practice. Because of this, the subject is not covered in the current (third) edition of the AITC Timber Design Handbook. The subject may have interest in connection with strength evaluation of some existing concrete-timber bridges or for special designs.

3.4 Structural Sandwich Panels.

3.4.1 Definition. A composite structure that comprises two facings, separated by and connected to a structural core that usually is less stiff and less dense, with the facings and core usually connected by an adhesive so that the composite cross-section of the composite structure exhibits much greater strength and stiffness than the strength and stiffness of the individual component parts. In structural applications involving bending, the behavior of the facings is analogous to the flange of a structural I-beam, while the behavior of the core is analogous to the web of the I-beam.

3.4.2 Design Guidelines.

3.4.2.1 Panels with Various Thin Facings and Foam Plastic or Other Lightweight Cores. Chapter 8 in American Society of Civil Engineers (ASCE) Structural Plastics Design Manual provides design procedures and equations for structural behavior and design, examples, and other guidelines; describes typical materials; and gives criteria for optimum proportions and an extensive list of references.

3.4.2.2 Panels with Concrete Facings. Chapter 6 in PCI Manual for Structural Design of Architectural Precast Concrete gives design guidance and criteria.

3.4.3 Facings. May be plywood, aluminum alloy, galvanized or stainless steel, fiberglass, pressed board, concrete, and numerous other materials. Plywood, pressed board, and other materials that support combustion shall not be used for the interior facing of panels unless given a permanent fire-retardant treatment. In general, dissimilar materials on opposite facings should be avoided, or their differing responses to environmental and structural conditions should be accurately taken into account in the design. Also, their performance in the sandwich should be confirmed by testing. Facings that exhibit large movement with thermal or moisture changes are unsuitable for use in most environmental conditions.

3.4.4 Cores. May be natural wood such as end-grain balsa, foam plastics, mechanically constructed cells of either grid or honeycomb construction, or expanded glass. See Chapter 1 in ASCE Structural Plastics Design Manual for typical core material properties. Where cellular plastics are used, the selection of the specific material shall be made in consultation with the NAVFACENGCOM Engineering Field Division's Fire Protection Engineer, to assure use of a fire-safe material.

3.4.5 Adhesives. Bond facing to cores using adhesives that provide shear and tensile bond strengths that are greater than the shear and tensile strengths of the core.

3.4.6 Proportioning. See Chapter 8 in ASCE Structural Plastics Design Manual for procedures for proportioning the facings and core for adequate strength and stiffness to minimize the combined cost of core and facing materials. Procedures are also given for determining resistance to panel buckling, local face wrinkling, etc. The reference also gives procedures for determining stresses and deflections caused by thermal and moisture gradients.

3.4.7 Fastening. Fasteners must have sufficient shear, pull-out resistance, and bearing strengths to provide required safety factors against failure of panel supports due to dead loads, wind loads, seismic forces, or other design loads. The design should provide for the tolerances required for practical fabrication and erection of the panel support system.

3.4.8 Proof-of-Design Tests. Proof-of-design tests are used to confirm the adequacy of the panel to meet specified structural, thermal, and other performance criteria. The structural criteria should include the effects of thermal and moisture gradients across the panel thickness. These produce deflection and, in the case of continuous panels with more than two lines of support, significant flexural and shear stresses. See Heger, Frank, Thermal Gradient Deflections and Stresses in Structural Sandwich Insulating Panels. Testing should include strength of fasteners.

3.4.9 Quality Control. A quality control program should be a part of panel manufacture requirements. As a minimum, this should include:

(1) Non-destructive tests for facing and core thickness and for uniformity of adhesive. Ultrasonic testing equipment provides one means for making such tests.

(2) Random sampling and testing for adhesive strength, core shear and tensile strength, and facing strength.

4.1 Scope.

4.1.1 Types of Material Covered. Few design standards are available for structural plastics and fiber-reinforced composites. Available design standards and reference sources for guidance in obtaining design criteria for plastics and composite materials that are to be used in structural applications are given in Paragraph 4.2. The following types of materials are covered:

(1) Fiberglass-reinforced plastics

(2) Thermoplastics

(3) Glass fiber, steel fiber, and organic fiber-reinforced concrete.

4.1.2 Structures Not Covered. The design criteria and guidance given herein do not cover aircraft or ship design.

4.1.3 Guidance. See Appendix B for applications guidelines and cautions.

4.2 Design Standards and Guidelines.

4.2.1 General. There is no general design specification for design of thermoplastic or fiberglass-reinforced plastic (FRP) components. Available design standards relate to a specific type of product for a limited range of applications. Some of these are given below.

General design guidance for structural applications of thermoplastics and fiberglass-reinforced plastics may be found in ASCE Structural Plastics Design Manual. This publication covers typical structural plastics materials, visco-elastic behavior of plastics, materials considerations for structural design, overall considerations for developing cost-effective designs in plastics, structural behavior of orthotropic plates and plates with large deflections, of beams and columns with thin wall configurations of orthotropic materials, of sandwich panels, and of thin rings, shells, and pipes with orthotropic materials; and fire performance considerations in the use of structural plastics. Additional general guidance for the selection of structural plastics is found in ASCE Structural Plastics Selection Manual. Both of the above manuals have extensive reference lists. Engineering Design Properties of GRP, Johnson, A.F., is also a useful reference.

4.2.2 Corrosion-Resistant Equipment - Fiberglass-Reinforced Plastics (FRP) Tanks, Ducts, and Miscellaneous Equipment. The following standards provide guidance for limited applications.

(1) Society of the Plastics Industry (SPI) Users Guides to RP Industrial Equipment.

#1 Tanks, October 1983

#3 Reprint for historical Record of NBS Voluntary Product Standard PS15-69, Custom Contact-Molded Reinforced Polyester Chemical-Resistant Process Equipment, January 1985.

#5 Structural Applications, June 1985.

(2) SPI, Quality Assurance Report, RTP Corrosion-Resistant Equipment.

(3) American Society of Mechanical Engineers (ASME), Section X of ASME Boiler and Pressure Vessel Code, Fiberglass Reinforced Plastic Pressure Vessels.

(4) American Society for Testing and Materials (ASTM), C581, Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass Fiber Reinforced Structures Intended for Liquid Service.

(5) ASTM C582, Standard Specification for Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment.

(6) ASTM D3299, Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Chemical-Resistant Tanks.

(7) ASTM D4021, Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks.

(8) ASTM D4097, "Standard Specification for Contact-Molded Glass-Fiber-Reinforced Thermoset Resin Chemical-Resistant Tanks.

(9) ASTM D3982, "Specification for Custom Contact-Pressure-Molded Glass-Fiber-Reinforced Thermosetting Resin Hoods.

(10) American Society of Civil Engineers (ASCE) Structural Plastics Design Manual.

(11) ASCE Structural Plastics Selection Manual.

(12) Relevant British Standard Institute (BSI) Specifications.

(13) Design of FRP Fluid Storage Vessels, Heger, F. J., in the ASCE Journal of the Structural Division.

4.2.3 FRP Pultruded Shapes. Reinforced plastics are fabricated in various structural shapes that are similar to rolled steel and aluminum members - wide flange and I-beams, channels, angles, rectangular tubes, and circular tubes - by the pultrusion process (similar to extrusion). The resulting fiberglass-reinforced plastic materials in these products almost always have highly oriented reinforcement with continuous filaments in the direction of the member length. These directional materials have much higher structural properties along the member axis than perpendicular to it. They may be considered to behave as orthotropic materials. Design procedures for such components are given in Chapter 7 of ASCE Structural Plastics Design Manual. Various manufacturers of these shapes publish design manuals with design criteria and tables, giving maximum loads for beams of various spans.

The following ASTM Standards cover pultruded structural shapes and fabricated items:

(1) ASTM D3918, Standard Definition of Terms Relating to Reinforced Plastic Pultruded Products.

(2) ASTM D3917, Standard Specification for Dimensional Tolerance of Thermosetting Glass-Reinforced Plastic Pultruded Shapes.

(3) ASTM D3647, Standard Practice for Classifying Reinforced Plastic Pultruded Shapes According to Composition.

(4) ASTM D4475, Test Method for Apparent Horizontal Shear Strength of Pultruded Reinforced Plastic Rods by the Short Beam Method.

(5) ASTM D4476, Test Method for Flexural Properties of Fiber Reinforced Pultruded Plastic Rod.

(6) ASTM D3914, Standard Test Method for In-Plane Shear Strength of Pultruded Glass-Reinforced Plastic Rod.

(7) ASTM D3916, Standard Test Method for Tensile Properties of Pultruded Glass-Fiber Reinforced Plastic Rod.

(8) ASTM D2996, Filament-Wound Reinforced Thermosetting Resin Pipe.

4.2.4 FRP Panels. The following publications provide guidance for selection, specification, and installation of FRP panels.

(1) ASTM D3841, Standard Specification for Glass Fiber-Reinforced Polyester Plastic Panels.

(2) SPI Recommended Installation Details for Fiberglass Reinforced Plastic Panels.

(3) ASCE Structural Plastics Design Manual.

4.2.5 Tension Membranes - Tents and Air-Supported Structures. Tension membranes are used in structures such as tents and air-supported enclosures and components. Air-supported structures include single membranes, enclosing an entire pressurized space, and closed cell double membrane, pressurized components that can be used for covering non-pressurized spaces. Fabrics used for such membranes are often composites of flexible plastic coating and inorganic or organic fiber. Three common types are fluoroplastic (PTFE) coated glass fiber, polyvinyl chloride (PVC) coated nylon or polyester fiber, and neoprene coated nylon or polyester fiber. The first type can be formulated to be non-combustible, a particularly important consideration for covering large spaces used for public assembly.

For guidance in designing tension membranes, see:

(1) ASCE Structural Plastic Design Manual, Chapters 6 and 9.

(2) ASCE State-of-the-Art Report on Air Supported Structures.

(3) Design Manual for Ground-Mounted Air-Supported Structures [Single Wall and Double Wall], U.S. Army Natick Laboratories.

A survey of past applications of fabric structures and guidance on rational application of the various structures of this type are given in Use of Tensioned Fabric Structures by Federal Agencies, by the National Research Council.

Recommended model code provisions for fabric structures have been published by the Architectural Fabric Structures Institute in Recommended Code Provisions.

See also Appendix B, Paragraph B.8, for supplementary information on tension membranes.

4.2.6 Thermoplastics. Structural design handbooks are published by some materials manufacturers. Material properties and design aids are also published in annual editions of Modern Plastics Encyclopedia, McGraw-Hill. See also ASCE Structural Plastics Design Manual and Selection Manual.

4.2.7 Glass Fiber-Reinforced Concrete (GFRC) Wall Panels. GFRC panels are used as exterior non-load-bearing wall panels on buildings. Often, light gage steel framing is used as a back-up structure, reducing the panel span to 2 feet or less. The following references describe current design practice with this composite material:

(1) PCI, Recommended Practice for Glass Fiber Reinforced Concrete Panels.

(2) PCI, Guide Specification for Glass Fiber Reinforced Concrete Panels.

(3) Council of American Building Officials, National Research Board, Report No. NRB-115, Sept. 1983, Glass Fiber Reinforced Concrete Panels, Prestressed Concrete Institute.

4.2.8 Fiber-Reinforced Concrete. Concrete and cementitious mortar is reinforced with special alkali-resistant, chopped-glass fibers, short steel fibers, or various organic plastic fibers to obtain enhanced strength, ductility, and toughness, compared to plain concrete and mortar. Design guidance and typical materials properties may be found in the following:

(1) ACI 544.1R, State-of-the Art Report on Fiber Reinforced Concrete. An extensive list of technical articles covering various types of fiber-reinforced concrete is included in this report.

(2) ACI 544.2R, Measurement of Properties of Fiber Reinforced Concrete.

(3) ACI SP-44, An International Symposium: Fiber Reinforced Concrete.

4.2.9 Polypropylene Fiber-Reinforced Slabs-on-Grade. Polypropylene fibers have been suggested as a replacement for welded wire fabric or other steel reinforcing, for control of shrinkage and temperature cracking. At this time, claims for this product have not been conclusively demonstrated. For a summary of the information available on fibrillated polypropylene used as concrete reinforcement, including references to test data, refer to Polypropylene Fibers in Concrete - What do the tests tell us?, Concrete Construction, April 1986.

4.2.10 FRP Reinforcement for Concrete. FRP is increasingly being considered as a replacement for carbon steel reinforcing in concrete structures. However, this technology is still evolving and performance is unknown. Therefore, do not use FRP as concrete reinforcement in structural applications unless a waiver is received from the Office of the Chief Engineer, NAVFACENGCOM (copied to Code 15C).

4.2.11 Availability of Repair Materials. Consider local availability of plastic and epoxy repair and replacement during the design process. Some products may be inexpensive to ship large quantities during construction, but cost-prohibitive to ship a small quantity during repairs.

APPENDIX A

APPLICATIONS GUIDELINES AND CAUTIONS FOR ALUMINUM STRUCTURES

A.1 General. Use aluminum structures in applications where their high initial cost (relative to conventional structural materials -- steel, reinforced concrete, and timber) is justified because of benefits expected from the following characteristics:

(1) Structural value - high strength to weight; lightweight.

(2) Economical fabrication - can be extruded or cast; has ease of workability and fabrication.

(3) Good corrosion resistance in many environments.

(4) Non-magnetic.

(5) Low maintenance cost in many environments.

(6) Lack of spark generation (with most aluminum alloys).

(7) High electrical and heat conductivity.

(8) High reflectivity of light in visible and infrared wavelengths.

The above characteristics lead to the selection of aluminum alloys for structural applications where low weight is essential, or where the life-cycle cost in a particular application is favorable because of good corrosion resistance and low maintenance costs relative to other structural materials, and in other special applications.

A.2 Application and Design Cautions. The designer of aluminum structures should keep in mind certain characteristics of the material that require significantly different design practice compared to design in structural steel.

A.2.1 Corrosion Resistance. Aluminum has a higher resistance to corrosion than do the usual alloys of structural steel, but it does not provide automatic protection against attacks from all corrosive environments. In particular, a marine environment is detrimental to some alloys. Also, care should be exercised when using aluminum under conditions in which electrolytic action can develop, such as in contact with concrete or with dissimilar metals such as steel.

(1) Marine Environment. Use caution and consult with NAVFACENGCOM HQ. Certain alloys (principally 5000 series) can give good service, provided that they are of proper temper.

(2) Isolation. Isolate aluminum in applications involving contact with dissimilar metals or with concrete. Isolation shall be achieved by use of coatings specified in the Design Standards listed in Section 2 or by use of materials that have been prequalified by NAVFACENGCOM HQ. Use of stainless steel in contact with aluminum, without isolation, will be permitted. However, isolation between metals is required where stainless steel may be in contact with both aluminum and carbon steel.

(3) Concrete. Aluminum should not be embedded in or in contact with concrete unless isolation is provided, since it may corrode in this environment.

(4) Oxygen. If oxygen is precluded from contact with the aluminum (buried or under plastic washers), accelerated corrosion may occur.

A.2.2 Modulus of Elasticity. The low modulus of elasticity (about 0.4 of that of steel) often requires special investigation of deflection and buckling. Design limits are often governed by local and overall crippling and buckling.

A.2.3 Coefficient of Thermal Expansion. The coefficient of thermal expansion of aluminum is about twice that of steel. However, because of a lower modulus of elasticity, stresses in aluminum alloy structures resulting from temperature changes or misalignments of parts often are lower than those in comparable steel structures.

A.2.4 Compatibility. Composite action or interaction with steel or concrete framing involves problems of incompatibility because of the difference in coefficients of thermal expansion and modulus of elasticity.

A.2.5 Lack of Well-Defined Yield Point. There is no clearly defined yield point. Further, a narrow spread exists between yield and ultimate strengths. It is often necessary to consider secondary and parasitic stresses, as such stresses become cumulative with each other and with primary stresses without the relief normally associated with yield of the material. Avoid stress raisers, such as notches; aluminum tends to tear easily in the presence of such stress raisers.

A.2.6 Welding Heat. Welding heat lowers the strength of most aluminum alloys in the heat-affected zone of the weld. This must be considered when designing welded connections for aluminum structures.

A.2.7 Fire Resistance. Published fire resistance ratings of aluminum structural elements are unavailable. Except in special circumstances, aluminum should not be used in primary structural elements where fire resistance ratings are required, because some alloys start to lose strength at temperatures as low as 200 degrees Fahrenheit (˚F.).

A.3 Additional Design Guidance. The following publications of the Aluminum Association provide additional guidance for design of aluminum structures:

- A Guide to Aluminum Extrusions.
- Aluminum Extrusion Applications Guide.
- Designation Systems for Aluminum Finishes.
- Standards for Anodized Architectural Aluminum.
- Aluminum Forging Design Manual.
- Aluminum Impacts Design Manual and Applications Guide.
- Standards for Aluminum Sand and Permanent Mold Castings.
- Special Report of the Mechanical Properties of Sand Cast Aluminum Alloy Test Castings.

A.4 Other Guidelines and Cautions. See Appendix A in MIL-HDBK-1002/3 for additional design guidance and cautions applicable to structural design in both aluminum and steel.

APPENDIX B

APPLICATIONS GUIDELINES AND CAUTIONS FOR STRUCTURAL PLASTICS AND FIBER-REINFORCED COMPOSITES

B.1 General. Applications guidelines are given in ASCE, Structural Plastics Design Manual, Chapter 4, Overall Consideration in Structural Design with Plastics. General criteria for selecting plastics materials are given in the above reference, Chapter 2, Behavior of Structural Plastics and in Chapter 3, Materials Criteria for Structural Design. A more comprehensive treatment of selection criteria is given in ASCE Structural Plastics Selection Manual, as well as in various references cited in the above ASCE manual.

B.2 Desirable Characteristics. The following characteristics of structural plastics make them desirable and cost effective for certain structural applications:

(1) Excellent corrosion resistance in many aggressive environments.

(2) Economical fabrication of complex geometries by molding, extruding, and other manufacturing processes; reduction in the number of separate parts to be assembled or fabricated. Since fabrication costs reduce as the number of identical parts increases, economic feasibility of various fabrication processes depends greatly on the number of identical parts, as well as on the type of materials and the size and shape of the desired components.

(3) Low unit weight of materials compared to metals such as steel.

(4) Reduced maintenance because of excellent corrosion resistance; fewer parts; smooth surface quality, texture, color, etc.

(5) High strength-to-weight ratios can be achieved with fiber-reinforced composites like fiberglass-reinforced plastics (FRP). Both thermoplastic and thermosetting types of plastics may be fiber-reinforced.

(6) Low dielectric properties are desirable for many electronics applications.

(7) Fire-resistant panels can be fabricated from fiber-reinforced concrete in relatively lightweight, thin-molded shapes that meet a variety of aesthetic objectives.

B.3 Limitations and Design Cautions.

(1) Apparent stiffness and strength reduce with long duration loads. These effects of visco-elastic behavior, known as creep and creep

rupture, respectively, are basic materials characteristics. These characteristics should be included as structural design criteria for each specific plastic or reinforced-plastic material.

(2) Severe environment (i.e., exposure to moisture and chemicals, elevated or depressed temperature levels, ultraviolet, and weathering) may degrade structural properties, depending on the type and composition of plastics and severity of the environment. These effects should be included as service design criteria for each specific plastic and reinforced-plastic material.

(3) Low stiffness and directional properties require special consideration of buckling and deflection in structural applications involving compression and bending.

(4) Lack of ductility with most plastics and reinforced plastics requires accurate stress analysis and design to eliminate stress concentrations and points of locally high stress. Secondary stresses produced by restraints to deformation caused by supports, discontinuities, stress raisers and concentrations, and environmental change should be determined and taken into account in the design.

(5) Low fracture toughness with some thermoplastics requires careful detailing to avoid notches and stress raisers, such as holes, abrupt changes in cross-section, and sharp corners.

(6) High coefficient of thermal expansion requires careful design to accommodate larger movements or to account for structural consequences of movement restraint. Some plastics also shrink during curing and some exhibit dimensional changes with changes in moisture.

(7) Limits on maximum service temperature must be established for each plastic material and must not be exceeded in structural applications. Few thermoplastics and conventional reinforced plastics can be used in environments above 200 degrees F. Many experience severe decay in structural properties at temperatures well below this level.

(8) Low fire resistance and combustion products that include toxic fumes exclude many plastics from structural applications in building construction. Performance of some plastics in fire conditions can be improved with the introduction of fire-retardant chemical additives or with the use of protective enclosures.

(9) For glass and steel fiber-reinforced concrete, long-term exposure to moisture and weathering usually produces a significant reduction in the strength properties, ductility, and toughness.

(10) Movements due to thermal and moisture change and restraint of such movement may induce significant stresses in molded panels of fiber-reinforced concrete. Because of relatively low ductility and because

weathering reduces strength and ductility, thermal loads may significantly stress the panel and thus lower the ability of the panel to resist other loads.

B.4 Design for Economical Fabrication. The cost-effective use of structural plastics for applications that require a large number of identical components requires consideration of both materials structural characteristics and their compatibility with the fabrication process. See Chapter 4 in ASCE Structural Plastics Design Manual for a molding design guide and descriptions of various fabrication processes.

B.5 Prototype Tests. When large numbers of a component are to be fabricated, prototype tests are often desirable to refine the design and to confirm design adequacy. Furthermore, a successful and properly designed prototype test program can justify the use of a less conservative design with a lower safety factor and potential savings in materials, weight, and cost.

B.6 Proof-of-Design Tests. Proof-of-design tests are used to confirm the adequacy of the component to meet specified structural, thermal, and other performance criteria. The structural criteria should include the effects of the expected service environment, including accelerated weathering where appropriate.

Acoustic emissions testing can be used to determine whether stresses are above certain threshold levels during structural testing of fiberglass-reinforced plastics components and products.

B.7 Quality Control. The plastics materials manufacturers, product or component manufacturers, and the product installer should all have adequate quality control programs. As a minimum, these should include:

(1) Appropriate quality control tests and inspections on basic resin and fiber-reinforcement materials.

(2) Visual inspections and non-destructive tests for thickness, absence of voids, and other deficiencies in uniformity of the material. Ultrasonic testing equipment can be a useful aid in testing for thickness, voids, delaminations, and the like.

(3) Visual inspections of field assembly of large components and erection or installation of plastics components such as building panels, structural members, ducts, tanks, etc. Inspection of field-installed mechanical fasteners, overlay joints, adhesive and heat-welded joints, and other connections.

B.8 Tension Membranes - Tents and Air-Supported Structures. As the name implies, tension membranes are capable of resisting applied loads only when they are stressed in tension. When they are not given sufficient initial tension, large changes in shape may result from fluctuating loads, such as wind load, producing unsatisfactory behavior like flapping, flutter, and excessive movement. In view of this, most tension structures are pretensioned prior to application of service loads, either by tensioning against external anchorage, and internal struts, or by internal air pressure. Once the tension structure has sufficient initial tension, it can resist applied distributed loads that produce tension, compression, and/or in-plane shear, so long as the principal compression resulting from the applied loads remains below the initial tension, and the combined initial tension and applied principal tension remain below the safe tensile strength limit.

Tension membranes differ from rigid shells because they cannot resist bending and transverse shear, and they must have sufficient initial tension to counteract membrane compression due to applied loads. Usually, the initial tension forces and the applied loads produce large deformations of tension structures, and the changes in structure geometry must be accounted for in accurate design analyses. However, if the final geometry of a tension structure, after application of initial tension and applied loads, can be estimated with sufficient accuracy or determined experimentally, the structure may be analyzed using the membrane analysis methods that are described in Chapters 6 and 9 of ASCE Structural Plastics Design Manual. Even when final shapes can only be roughly estimated, linear membrane analysis may be very useful for preliminary design purposes.

Tension structures require adequate anchorage to develop tension edge forces necessary to develop initial tension in the membrane and edge reactions caused by applied loads. Anchorage strength frequently is developed by providing sufficient weight in foundations or by anchoring into the ground with earth anchors having adequate pullout strength.

When initial or final stresses are larger than the safe strength of the skin fabrics, tension membranes can be reinforced with cables of nylon, aramid, fiberglass, or steel. Such reinforcement may also be required if significant concentrated loads must be supported.

Construction Criteria Manual - Department of Defense (DOD) 4270.1-M. Copies can be obtained from the U.S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

Naval Facilities Engineering Command - Copies for Design Manuals (DM), Publications (P), Naval Facilities Guide Specifications (NFGS), and Military Handbooks (MIL-HDBK) can be obtained from the U.S. Navy Publications Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

DM-2.04	Concrete Structures
MIL-HDBK-1002/7	Seismic Site Response Spectra
DM-2.08	Blast Resistant Structures
DM-2.09	Masonry Structural Design for Buildings
DM-7.01	Soil Mechanics
DM-7.02	Foundations and Earth Structures
DM-7.03	Soil Dynamics, Deep Stabilization and Special Geotechnical Construction
DM-50	NAVFAC Index to Engineering and Design Criteria
P-34	Engineering and Design Criteria for Navy Facilities
P-355	Seismic Design for Buildings
P-355.1	Seismic Design Guidelines for Essential Buildings
P-397	Structures to Resist the Effects of Accidental Explosions
NFGS-03300	Cast-in-Place Concrete
NFGS-03410	Precast Structural Concrete
NFGS-03420	Precast Prestressed Concrete
NFGS-05500	Metal Fabrication
MIL-HDBK-1002/5	Timber Structures
MIL-HDBK-1008	Fire Protection for Facilities Engineering, Design and Construction

Aluminum Association (AA) specifications, standards, manuals, guides, and reports. The Aluminum Association, 818 Connecticut Ave., NW., Washington, DC 20006.

A Guide to Aluminum Extrusions, 6.
Aluminum Extrusion Applications Guide, 7.
Aluminum Forging Design Manual, 15.
Aluminum Impacts Design Manual and Applications Guide, 16.
Commentary on Specifications for Aluminum Structures, 31.
Designation System for Aluminum Finishes, 45.
Engineering Data for Aluminum Structures, 33.
Illustrative Examples of Design, 32.
Special Report of the Mechanical Properties of Sand Cast Aluminum Alloy Test Castings, 19.
Specifications for Aluminum Structures, 30.
Standards for Aluminum Sand and Permanent Mold Castings, 18.
Standards for Anodized Architectural Aluminum, 46.
Welding Aluminum, WA-4.

American Concrete Institute (ACI) code and committee reports. American Concrete Institute, Box 19150, Redford Station, Detroit, MI 48219.

SP-44. An International Symposium: Fiber Reinforced Concrete.
ACI-318. Building Code Requirements for Reinforced Concrete, 1981.
ACI 544.2R. Measurement of Properties of Fiber Reinforced Concrete.
ACI 544.1R. State-of-the-Art Report on Fiber Reinforced Concrete, 1982.

American Institute of Timber Construction (AITC) handbooks. American Institute of Timber Construction, 333 West Hampden Ave., Englewood, CO 80110.

Timber Design Handbook, 3rd Ed., 1986.
Timber Design Handbook, 2nd Ed., 1974 (Out of print. Contains information on composite concrete-timber bridge decks not covered in 3rd edition.)

American Society of Civil Engineers (ASCE) manuals and reports. American Society of Civil Engineers, 345 East 47th St., New York, NY 10017.

State-of-the-Art Report on Air Supported Structures, 1979.
Structural Plastics Design Manual, 1983.
Structural Plastics Selection Manual, 1985.

Architectural Aluminum Manufacturers Association (AAMA) manuals and guide specifications. Architectural Aluminum Manufacturers Association, 2700 River Road, Des Plaines, IL 60018.

Curtain Wall Design Guide Manual (CW-1-9).
Curtain Wall Manual #11 (CW-11): Design Wind Loads for Buildings and Boundary Layer Wind Tunnel Testing Manual.
Curtain Wall Manual #12 (CW-12): Structural Properties of Glass.
Methods of Test for Metal Curtain Walls (AAMA 501-83).

Architectural Fabric Structures - Use of Tensioned Fabric Structures by Federal Agencies, 1985. Copies can obtained from the National Research Council, 2101 Constitution Avenue, NW., Washington, DC 20418.

Boiler and Pressure Vessel Code, Section X, 1983. American Society of Mechanical Engineers (ASME), 345 East 47th Street, New York, NY 10017-2398.

British Standards Institute (BSI), 2 Park Street, London W1A 2BS, England.

Explanatory supplement to BS4994. Specification for vessels and tanks in reinforced plastics.

Specification for vessels and tanks in reinforced plastics.

American Society for Testing and Materials (ASTM) standards. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM C581 Standard Specification for Determining Chemical Resistance of Thermosetting Resins Used in Glass Fiber Reinforced Structures Intended for Liquid Service.

ASTM C582 Standard Specification for Control-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment.

ASTM D2996 Filament-Wound Reinforced Thermosetting Resin Pipe.

ASTM D3299 Standard Specification for Filament-Wound Glass-Fiber Reinforced Thermostat Resin Chemical-Resistant Tanks.

ASTM D3647 Standard Practice for Classifying Reinforced Plastic Pultruded Shapes According to Composition.

ASTM D3841 Standard Specification for Glass Fiber-Reinforced Polyester Plastic Panels.

ASTM D3914 Standard Test Method for In-Plane Shear Strength of Pultruded Glass-Reinforced Plastic Rod.

ASTM D3916 Standard Test Method for Tensile Properties of Pultruded Glass-Fiber Reinforced Plastic Rod.

ASTM D3917 Standard Specification for Dimensional Tolerance of Thermosetting Glass-Reinforced Plastic Pultruded Shapes.

ASTM D3918 Standard Definition of Terms Relating to Reinforced Plastic Pultruded Products.

ASTM D3982 Specifications for Custom Contact-Pressure-Molded Glass-Fiber-Reinforced Thermosetting Resin Hoods.

ASTM D4021 Standard Specifications for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks.

ASTM D4097 Standard Specification for Contact-Molded Glass-Fiber-Reinforced Thermoset Resin Chemical-Resistant Tanks.

ASTM D4475 Test Method for Apparent Horizontal Shear Strength of Pultruded Reinforced Plastic Rods by the Short Beam Method.

ASTM D4476 Test Method for Flexural Properties of Fiber Reinforced Pultruded Plastic Rod.

Design Criteria for Bolted and Riveted Joints, Fisher, John, and Struik, John - John Wiley & Sons, 1974.

Design Manual for Ground-Measured Air-Supported Structures (Single and Double-Wall), Technical Report 69-59-6P, 1969, U.S. Army Natick Laboratories, Natick, MA 01760.

Design of FRP Fluid Storage Vessels, Heger, Frank J., Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, November 1970.

Engineering Design Properties of GRP, Johnson, A.F., The British Plastics Foundation, 5 Belgrave Square, London SW1X 8PH, England, 1979.

Glass Fiber Reinforced Concrete Panels, September 1983, National Research Board, Report No. NRB-115, Council of American Building Officials, Building Officials and Code Administrators International, Inc., 17296 South Halsted Street, Homewood, IL 60430.

Modern Plastics Encyclopedia, McGraw-Hill, New York, NY, 1985.

National Design Specifications for Wood Construction, 1977, National Forest Products Association, 1619 Massachusetts Ave., NW., Washington, DC 20036.

Naval Facilities (NAVFAC) Engineering Command. Copies of NAVFAC Design Manuals (DMs) and Military Handbooks (MIL-HDBKs) can be obtained from the U.S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

MIL-HDBK-1002/1 Structural Engineering General Requirements
MIL-HDBK-1002/2 Loads
MIL-HDBK-1002/3 Steel Structures

Polypropylene Fibers in Concrete - What do the Tests Tell Us?, Concrete Construction Magazine, April 1986. Concrete Construction Publications, Inc., 426 South Westgate, Addison, IL 60101.

Prestressed Concrete Institute (PCI) Manuals and Guides for Precast and Prestressed Concrete. Prestressed Concrete Institute, 201 North Wells St., Chicago, IL 60606.

Design Handbook, 3rd Edition, 1985.
Guide Specifications for Glass Fiber Reinforced Concrete Panels, SPC-120-82.
Manual for the Design of Hollow-Core Slabs, MNL-126.
Manual for Structural Design of Architectural Precast Concrete, MNL-121, 1977.
Recommended Practice for Glass Fiber Reinforced Concrete Journals (available as reprint from PCI Journal, Vol. 26, No. 1, Jan.-Feb. 1981).

Recommended Code Provisions. Architectural Fabric Structures Institute, 1800 Pickwick Avenue, Glenview, IL 60025-1377.

Society of the Plastics Industry, Inc., 355 Lexington Ave., New York, NY 10017.

Quality Assurance Report - RTP Corrosion-Resistant Equipment.
Recommended Installation Details for Fiberglass Reinforced Plastic Panels.

Standard Specifications for Highway Bridges, American Association of State Highway and Transportation Officials (AASHTO), 444 North Capitol Street, NW., Washington, DC 20004.

Structural Standards for Steel Antenna Towers and Antenna Supporting Structures - RS-222-C, March 1976. Electronics Industries Association (EIA), 2001 Eye Street, NW., Washington, DC 20006-1807.

Thermal Gradient Deflections and Stresses in Structural Sandwich Insulating Panels, Proceedings of the Conference on Applied Techniques for Cold Environments, ASCE, May 17-19, 1978. The American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017.

Welding Handbook, 6th Edition, 1973. American Welding Society, 2501 N.W. 7th St., Miami, FL 33125.

CUSTODIAN:	PREPARING ACTIVITY:
NAVY-YD	NAVY-YD
	PROJECT NO.
	FACR-0189